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STUDY OF THE EFFECTS OF VARIOUS PROPELLER CONFIGURATIONS ON THE FLOW ABOUT A SHROUD

By
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LIST OF SYMBOLS

SYMBOL		UNITS
T_t	Total thrust	lb
T_p	Propeller thrust	lb
T_s	Shroud thrust	lb
H	Total head rise through propeller	lb/ft^2
P	Static pressure at shroud surface	lb/ft^2
r_h	Radius of propeller hub	in, ft
r_i	Minimum radius inside shroud	in, ft
r_o	Maximum radius outside shroud	in, ft
r_m	Mean radius	in, ft
D_m	Mean diameter	in, ft
b	Blade chord	in, ft
n	Rotational speed	rev/sec
C_L	Lift coefficient	
C_D	Drag coefficient	
C_T	Thrust coefficient $\frac{T}{\rho n^2 D^4}$	
C_P	Power coefficient $\frac{P}{\rho n^3 D^5}$	
ρ	Density of air	$lb\ sec^2/ft^4$
ϕ	Pitch angle	degrees
η	Propulsive efficiency $\frac{C_T}{C_P} \lambda$	
λ	Advance ratio $\frac{V}{nD}$	

SUMMARY

An investigation of a model shrouded propeller was conducted to determine the nature of the flow about the shroud and how it could be affected by various propeller configurations. From preliminary investigations it was concluded that the location, chord wise, of the propeller in the shroud was not critical. However, it did appear that the twist distribution along the radius of a standard propeller blade could be altered to give better flow characteristics around the shroud.

In order to investigate the effect of various propeller configurations on the flow about the shroud, the minimum area position of the shroud was chosen for the propeller location. Three five-bladed propellers were constructed with different blade width distribution, twist distribution, and angle of incidence. The object of the blade design was to move as much air as possible past the surface of the shroud in an effort to induce as high a velocity as possible around the leading edge of the shroud. The model work showed that with properly designed blades the desired effect could be obtained with an over-all increase in the thrust produced for a given power input.

Work was then shifted to a 5.5 foot diameter shroud mounted on a small pusher aircraft. To test the principles developed on the model shroud a two bladed aluminum propeller of constant pitch angle and constant chord was constructed to be interchangeable with the standard two bladed propeller previously fitted to the shroud.

The aluminum blades allowed for twisting of the propeller in order to study the effect of modified distribution of angle of attack along the radius of the blade on the flow around the shroud.

By twisting a higher angle into the propeller tips near the shroud surface, it was possible to induce a higher velocity around the shroud surface and, as in the case of the model, increase the thrust produced by the shroud for a given power input.

INTRODUCTION

The open propeller used for aircraft propulsion has always suffered from the lack of ability to produce a large thrust in the static and low velocity regions. This lack of thrust has been tolerated in order to gain maximum efficiency from the propeller at cruising speed. The variable pitch propeller is able to overcome partly the low speed deficiency by reducing the angle of attack of the blade for low speed and thus developing more revolutions per minute and more power for the acceleration through the low speed range.

In the case of helicopters the large static thrust required is obtained by use of a very large diameter rotor. No limit has yet been reached on the diameter of rotor that can be built, and the lifting ability of the helicopter so far has been limited only by the power one is willing to expend and the size of machine one is willing to build. However, the helicopter as such is definitely limited in forward flight speed by the complexities of the large rotor system in general use.

Neither the helicopter rotor nor the open propeller develop the maximum possible static thrust for the available power for a fixed diameter of the propeller due to tip losses and other losses which are unavoidable. A vertical lifting device of limited available power and limited diameter needs some principle whereby it can more nearly realize the maximum possible static thrust. The shrouded propeller offers one means of greatly improving the static thrust of a given propeller.

The shrouded propeller has been investigated on several occasions for various reasons and possible applications. In Germany, Krüger did an extensive study of the shroud to determine the effect of such items as power loading, solidity, and the thrusts produced by the shroud and the propeller.[1] His study included various shroud shapes and configurations tested statically and with advance ratios varying from 0 to 1.4.

Platt in the United States studied dual-rotating propellers in shrouds designed specifically for takeoff and cruise configurations.[2] Platt measured the approximate velocity distribution in front of and behind the dual-rotating propellers operating in the shroud. Comparison of the velocity profile ahead of the propellers with one behind the propellers seemed to indicate that the outer portion of the propeller was adding no energy to the flow and that it was slowing down this outer portion of the flow as it passed through the propellers. The fact that Platt experienced leading edge separation on his shroud except at high rotational speeds also indicated possible ineffectiveness of the propeller tips.

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1. Krüger, W. On Wind Tunnel Tests and Computations Concerning the Problem of Shrouded Propellers (NACA Technical Memorandum No. 1202). (Washington, D.C., 1949), pp. 41-42.

2. Platt, Robert J. Static Tests of a Shrouded and an Unshrouded Propeller (NACA Research Memorandum No. L7H25). Washington, D.C., 1948), pp. 8-11.

Hubbard studied the shrouded propeller to determine the noise level it produced as compared to the open propeller.[3] Also along with this study the effect of tip clearance on thrust of the shrouded propeller was determined.

In these studies the general conclusion was that a shroud-propeller combination could be developed that would give a static thrust considerably greater than a standard propeller.

In recent years the shrouded propeller concept has received new impetus by the introduction of such devices as flying platforms, aerial jeeps, and flying crane type devices where the primary interest is in developing a high static thrust more or less continuously. Also some study has gone into the possibility of utilizing the shrouded propeller on a pusher airplane. In this configuration the objection of carrying a shroud is offset by utilizing the shroud area as the stabilizing surfaces as well as for its thrust augmentation effect at low speed for high acceleration and short takeoff run.

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3. Hubbard, Harvey H. Sound Measurements of Shrouded Propellers at Static Conditions (NACA Technical Note No. 2024). (Washington, D.C., 1950).

EQUIPMENT AND TEST PROCEDURE

Model work was conducted for the static case only. A shroud of 12 inches outside diameter was mounted to produce thrust downward (Figure 1). Thrust was measured by mounting the entire apparatus on a platform scale. Horsepower output of the 120 volt electric motor was determined by measuring the torque of the motor and the rotational speed. Shroud thrust was determined from pressure distributions taken at twenty points on the shroud surface. In order to record this pressure distribution a photomanometer incorporating twenty tubes, each capable of measuring up to ten inches of water pressure, was used.

The shroud thrust was calculated by taking the pressure at each point on the shroud and assuming that this pressure acted on the entire ring with frontal area equal to 2π rdr where r is the distance of the point from the center of the shroud. The value of 2π Pr for each point on the shroud was plotted against the radius from r_i to r_o. From this plot the thrust was obtained by graphical integration were the area enclosed in the curve represented the shroud thrust without losses due to mounting supports. In the case of the model shroud tested the leading edge was unobstructed, and the losses were considered to be negligible. However, in the case of the full scale shroud mounted on the pusher airplane, fifteen per cent of the calculated thrust was discounted to take into account the area of the leading edge of the shroud unavailable at the mounting supports.

Total thrust of the shrouded propeller was obtained by first setting the desired amount on the scale and then increasing the power to the propeller until the scale balanced.

As a check on the method of obtaining the shroud thrust, a survey of the total head rise behind the propeller was made; and a graphical integration was performed in a manner similar to that for finding the shroud thrust to determine the thrust of the propeller alone according to:

$$T_p = \int_{r_h}^{r_i} 2\pi Hr dr$$

The measured total thrust and the sum of the calculated shroud thrust and propeller thrust checked closely. The maximum error was found to be less than six per cent in all cases.

The full scale tests were performed outdoors. An aluminum and fiberglass shroud with a diameter of 5.5 feet was mounted behind the trailing edge of an Anderson-Greenwood-14, two-place pusher aircraft. The cross section of the shroud is shown in Table (3). This was a developed section resulting from modification of an NACA 4416 airfoil section. The following devices were used to obtain information as to the nature of the flow around the shroud:

1. A ten static-tube mast to measure inflow velocity profile

2. A ten static-tube pressure belt to measure the pressure distribution at the shroud surface (Figure 3a)

3. A twenty total-head tube mast to measure velocities behind the shroud

4. An adjustable total-head tube to measure boundary layer thickness of separated zone

5. A shear meter to test for laminar separation at the leading edge of the shroud (Figure 3b)

6. Wool and nylon tufts to check direction of flow and extent of separation

7. Naphthalene spray to make sublimation studies of the boundary layer flow on the shroud and propeller leading edges

The naphthalene was dissolved in petroleum ether, and the mixture was sprayed dry in the form of a uniform white coating. During the test the varying magnitudes of the shear in the boundary layer sublimed the coating of naphthalene at varying rates. Thus the naphthalene in areas where high shear in the flow exist was sub-limed away more rapidly leaving a thicker coating of naphthalene in the areas of low shear.

8. A twenty tube photomanometer to record pressure readings

9. A 0-1000 pound dynamometer to measure total thrust of the shrouded propeller

10. The aircraft tachometer and manifold pressure gage to determine the power output of the Continental C-90 engine

A standard propeller with tips cut to fit the shroud and a uniform pitch (modified twist) constant chord aluminum propeller were tested with the shroud. The modified twist propeller was first tested with constant pitch along the radius. Two additional tests were made with an increase in the pitch angle of four and seven degrees at the tips of the propeller.

For both propellers the total static thrust was measured at several power settings and the results plotted in Figure (4).[4] To obtain data for the moving case the total thrust was measured by ground towing a vehicle with the aircraft. The towed vehicle was maintained at constant speed with brakes, and a dynamometer in the towing cable measured the thrust. From a measure of the pressure distribution on the shroud the thrust of the shroud was computed at several different velocities according to:

$$T_s = \int_{r_i}^{r_o} 2\pi Prdr$$

The results of these tests appear in Figure (5).

4. Stone, Arthur. A Study of Shrouded vs Unshrouded Propellers (Department of the Navy, Bureau of Aeronautics Research Division Report No. DR-1750). (Washington, D.C., 1955), p. 10, Figure 1.

DISCUSSION OF RESULTS

A. MODEL

Several preliminary investigations were made using the shroud of 12 inches diameter and model airplane propellers. By operating propellers at several chordwise positions in the shroud little difference was found in the amount of thrust produced for an equal power input. The minimum area was therefore chosen for all future tests. Former investigators used the minimum area of the shroud in almost every instance.

Measurements of the inflow velocity near the propeller did not show a uniform inflow as is assumed in the design of standard open propellers, but rather a velocity distribution that was almost parabolic in nature being much greater near the shroud than at the center. Platt of NACA measured a similar inflow velocity distribution with dual-rotating propellers in a shroud, but he assumed that the velocity profile became uniform at the propeller disc for the design of the propellers.[5] Krüger in Germany in 1944 tested a propeller designed upon the basis of non-uniform inflow velocity profile but did not find the results sufficiently gratifying to warrant further investigation. In the data presented for this propeller the efficiency at low advance ratios was higher with the higher blade angles than for the standard propeller.[6]

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5. Platt, Static Tests of a Shrouded and an Unshrouded Propeller, pp. 6 and 37.

6. Krüger, Wind Tunnel Tests, pp. 10, 15, 59-60.

In the present model test it was decided to further investigate the effects of a propeller designed for the non-uniform inflow distribution and particularly to investigate the possibility of altering this inflow velocity in such a way as to increase the flow at the shroud surface and thus induce a higher portion of the thrust on the shroud.

Using the approximate inflow velocity profile measured at the inlet to the model shroud, a calculation was carried out to determine the pitch angle variation that would exist on a propeller blade operating in this profile with constant angle of attack at every station along its radius. The results showed that the pitch angle was very nearly constant. Therefore, the first of the three five-bladed propellers was constructed with uniform pitch of 45° and constant chord. This propeller was always stalled due to the high angle of attack on the blades. The second propeller was constructed with wider chord at the tip than at the root and a tip pitch angle of 20°. This propeller operated satisfactorily and tufts attached to the shroud indicated that the flow was attached completely; whereas with the standard propeller, the flow behind the propeller was separated from the shroud. The total thrust per horsepower was also considerably higher than for the standard propeller. From pressure distribution measurements, the shroud thrust was computed to be approximately 52% of the total thrust. The third propeller was designed with uniform pitch angle of 20°. In order to determine the chord distribution, a constant thrust for equal increments of disc area was assumed; and the chord was determined according to the blade element theory by Dommasch.[7] Dommasch gives the following equation for the thrust of a blade element:

$$dT = \frac{\rho^2 n^2 D^2 b dr}{2 \cos^2 \phi} (C_L \cos \phi - C_D \sin \phi) \qquad 2.1$$

The mean diameter (D_m) and the width (Δr) of each blade element was selected by dividing the entire disc area of the propeller into six concentric and equal areas. It was further assumed that equal thrust would be developed at each of the six areas. Assuming a total thrust of fifteen pounds, each element of the propeller would be required to develop one half pound of thrust. The pitch angle (ϕ) was held constant at 13^o and an angle of attack of 7^o was assumed. At 7^o angle of attack a lift coefficient (C_L) of 0.6 and a drag coefficient (C_D) of 0.01 were assumed. The rotational speed for the design condition was set at 200 revolutions per second.

Solving equation 2.1 for the chord b:

$$b = \frac{2 \Delta T \cos^2 \phi}{\rho^2 n^2 D^2 \Delta r (C_L \cos \phi - C_D \sin \phi)}$$

Table (1) gives the tabulation of calculated results.

7. Dommasch, Daniel O. Elements of Propeller and Helicopter Aerodynamics (New York, 1953), pp. 33-37.

TABLE I Tabulated Results of Propeller Calculation

Area	r	r_m	D_m	b
1	0.74	2.37	4.74	2.15
2	0.58	3.03	6.06	1.70
3	0.49	3.57	7.13	1.45
4	0.44	4.03	8.06	1.25
5	0.39	4.45	8.90	1.15
6	0.36	4.82	9.64	1.10

The blades of this propeller were wide at the root and became narrow at the tip. This propeller gave the highest total thrust per horse-power of any of the propellers tested (Figure 4). The flow around the shroud was completely attached with good diffusion of the flow behind the propeller. The shroud thrust for this propeller No. 3 was computed to be approximately 55% of the total thrust over a wide range of power input. The shroud thrust was computed from pressure distribution according to:

$$T_s = \int_{r_i}^{r_o} 2\pi \, Prdr$$

The propeller thrust was computed from total head rise behind the propeller according to:

$$T_p = \int_{r_h}^{r_i} 2\pi \, Hrdr$$

Table (2) gives the approximate percentage of shroud thrust and propeller thrust corrected for 100 per cent total thrust.

TABLE 2 Percentages of Shroud Thrust and Propeller Thrust for Model Shrouded Propeller

Total Thrust, lb	3	4	5	6	7	8	9
$\frac{T_s}{T}$	52.3	55.0	55.1	56.5	54.5	58.0	55.7
$\frac{T_p}{T}$	47.7	45.0	44.9	43.5	44.5	42.0	44.3

B. FULL SCALE

Tests on a full scale shroud mounted on a two-place pusher aircraft were conducted using first the conventional propeller designed for an assumed constant inflow velocity distribution and second the propeller designed to more nearly match the actual inflow velocity distribution at the propeller disc due to the presence of the shroud.

In the static case with the standard propeller operating in the shroud it was found that laminar separation occurred on the leading edge of the shroud. Tufts placed at the leading edge showed a disturbance taking place about one or two inches inside the shroud (Figure 9). An exploration of the shroud leading edge with a shear meter (Figure 3b) revealed that the point of laminar separation occurred on the inner surface of the shroud approximately two or three inches from the forwardmost point on the leading edge. The inflow and exit velocity profiles for the static case were measured and typical distributions appear in Figures (6) and (7) for the two propellers in the shroud. Figure (8) shows a sublimation study of the two propellers and the effect of the separated flow on the standard propeller tip. From the various studies with tufts (Figure 9), sublimation, boundary layer thickness measurements, and measurements with a shear meter (Figure 3b) at the surface of the shroud, the descriptions of the flow fields around the shroud were arrived at as shown in Figures (10) and (11).

The flow around the leading edge of the shroud was found to be very unstable and easily affected by a slight degree of cross wind. A cross wind from one side would tend to attach the flow on the opposite side of the shroud and further separate it on the side from which the cross wind came. Once the separation occurred, the depth of the separated zone increased sharply until at the propeller disc it reached a depth of two or three inches. Figure (8) shows the effect of this separated zone on the outer portion of the standard propeller. From the pattern left by the unevaporated naphthalene, the sudden change in the operating angle of attack of the blade can be seen approximately three inches in from the tip.

Upon integrating the pressure distribution, the shroud thrust was found to be quite low and only about 20% of the total thrust. With forward motion the shroud became unseparated ahead of the propeller at forward velocities of about 15 to 20 feet per second. At this point the shroud pressure distribution changed abruptly and the integrated thrust of the shroud increased to about 25% of the total thrust. From this point on the shroud thrust dropped steadily with increasing forward velocity.

Upon checking the work of Krüger, where the shroud thrust was measured directly, it can be seen that in nearly every case examined the shroud thrust coefficient decreased steadily from a maximum in the static case as the ratio of advance was increased.[8] Then at some value of the ratio of advance depending upon many factors such as blade angle, shroud shape, etc., the thrust of the shroud increased suddenly and then resumed its decrease as the ratio of advance continued to increase.

The present investigation points out clearly the mechanism of this thrust jump, namely, separation on the leading edge. This thrust jump did or did not occur, depending upon the leading edge radius, the camber of the shroud section, and the pitch angle of the propeller. A small leading edge radius coupled with a large blade pitch angle was most conducive to this thrust jump. The more severe these items became the higher the ratio of advance needed to be in order to precipitate the jump. Krüger's work showed that by decreasing the sharpness of the leading edge radius by use of what he called a nose split ring, the higher blade pitch angles (which were most suitable for large ratios of advance) could be used to create high static thrust with thin shroud sections. A thick shroud with a large leading edge radius gave the same result, but it is less desirable than a thin shroud from the drag consideration at large ratios of advance.

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8. Krüger, Wind Tunnel Tests, pp. 56-61.

In the present investigation it was found that the pressure distribution around the leading edge of the shroud very closely resembled the pressure distribution associated with a laminar separation for the two-dimensional airfoil.[9] This pressure distribution is characterized by a relatively small negative pressure peak followed by a leveling off of the pressure behind this peak into a well defined plateau. The long plateau, as shown in Figure (12) for the static case with the standard propeller, is characteristic of laminar separation. The result of this laminar separation was a marked decrease in the peak negative pressure compared to the non-separated airfoil, resulting (as in the case of the shroud) in a decrease in the amount of thrust produced by the shroud. With increasing ratio of advance, a point was reached where the flow became attached. At this point the pressure pattern around the leading edge of the shroud experienced a sudden change in such a way as to give a higher shroud thrust. This sudden change was evidently precipitated when the pressure created by forward motion became sufficient to overcome the adverse pressure gradient causing the laminar separation on the leading edge of the shroud. This sudden change in the pressure pattern accounts for the thrust jump as recorded in Krüger's measurements.

Several possible methods of eliminating this shroud leading edge separation exist. The split ring as used by Krüger is one

9. Norbury, J. F. and Crabtree, L. F. A Simplified Model of the Incompressible Flow Past Two-Dimensional Aerofoils RAE Technical Note No. 2352, 1955. p. 13, Figure 1.

solution; but if the shroud were to be used at any appreciable speed, some arrangement would have to be made to retract or otherwise do away with the split ring. The same result might be achieved by use of an inflatable leading edge, as suggested by Rebuffet for a wing, similar to a de-icer boot, which could be inflated to give a large leading edge radius to eliminate separation at low ratios of advance and then be deflated to give a small leading edge radius on a thin low drag shroud.[10]

At the beginning of the present investigation, tests were made to investigate the use of boundary layer control to reduce separation on the shroud. Some success was obtained with perforated suction boundary layer control applied to the separated area ahead of the propeller. However, the suction system was able to attach the flow only intermittently. Measurements revealed that the suction pressure available was insufficient to overcome the pressure of the flow induced by the high velocity that existed around the leading edge at the instant the flow became attached. Further tests with boundary layer control are suggested when a better suction system is available.

Since it appeared that good flow attachment was achieved with the model shroud using a uniform pitch propeller, this same method was tried on the larger shroud. The best model propeller constructed had a high solidity with its five wide chord blades. To

10. Rebuffet, Pierre. Aérodynamique Expérimentale 10th ed., Paris et Liège, Librairie Polytechnique Ch. Béranger, 1950, pp. 445-446.

increase the solidity of the larger propeller having only two blades the tips next to the shroud were made as wide as the rest of the blade. The inflow velocity distribution again called for nearly a constant pitch angle at each station on the blade.

The modified twist propeller was constructed of aluminum with blades of constant chord and no twist. The aluminum blades made it possible to investigate by twisting the effect of increasing the pitch angle at the tip of the propeller upon the circulation of the shroud. It was felt that by thus increasing the amount of work done at the propeller tip, the flow around the leading edge of the shroud could be induced to higher velocities. This increase in velocity would increase the negative pressure about the leading edge and give greater thrust from the shroud. Positive results were obtained along this line showing that the shroud thrust could be increased slightly in this manner. No complete series of tests were conducted to determine the optimum twist distribution for this propeller because it was felt that once the propeller was closely matched to the potential flow of the shroud little more improvement could be obtained along this line. If the propeller were optimized for the static case, it would be less than optimum for all other cases of forward motion. At constant power setting the propeller rotational speed increased very little with increasing forward velocity which gave good indication that the propeller was maintaining a steady load distribution along its radius. Also a sublimation test of the propeller at 20 miles per hour (Figure 13) showed that the angle of attack changed little from the static condition. The pressure distribution on the shroud changed gradually and uniformly with increasing velocity which also indicated that the propeller was maintaining good circulation around the shroud.

As an over-all comparison of the standard propeller and the modified twist propeller in the shroud, the thrust coefficient, power coefficient, and propulsive efficiency were compared for both propellers at ratios of advance from 0 to 0.3 (Figure 14). Throughout this region the propulsive efficiency of the modified twist propeller remained increasingly higher.

CONCLUSIONS

Model work with high solidity shrouded propellers showed that a propeller could be designed to match the non-uniform inflow velocity distribution of a shrouded propeller. Certain possibilities exist as to the chord width distribution along the radius, the pitch distribution, and the manner in which the propeller disc loading is apportioned in order to obtain the maximum thrust from a shrouded propeller of given diameter and power available.

Full scale tests on a shrouded propeller embodying the principles developed during the model tests showed that an over-all increase in thrust could be obtained over the standard propeller operating in a shroud. Further it was shown that the greater part of this improvement came from the improvement of the flow at the shroud surface which greatly increased the portion of the thrust developed by the shroud.

In general, by some means of apportioning a greater amount of work at the tip of a shrouded propeller as compared to the rest of the propeller disc, the flow about the shroud can be improved with a resultant increase in the shroud thrust and a corresponding higher total thrust.

BIBLIOGRAPHY

A. Books

Dommasch, Daniel O. Elements of Propeller and Helicopter Aerodynamics. New York, Pitman, 1953.

Kucheman, Dietrich and Weber, Johanna. Aerodynamics of Propulsion. New York, McGraw-Hill, 1953.

Rebuffet, Pierre. Aérodynamique Expérimentale 10th ed., Paris et Liège. Librairie Polytechnique Ch. Béranger, 1950.

B. Reports

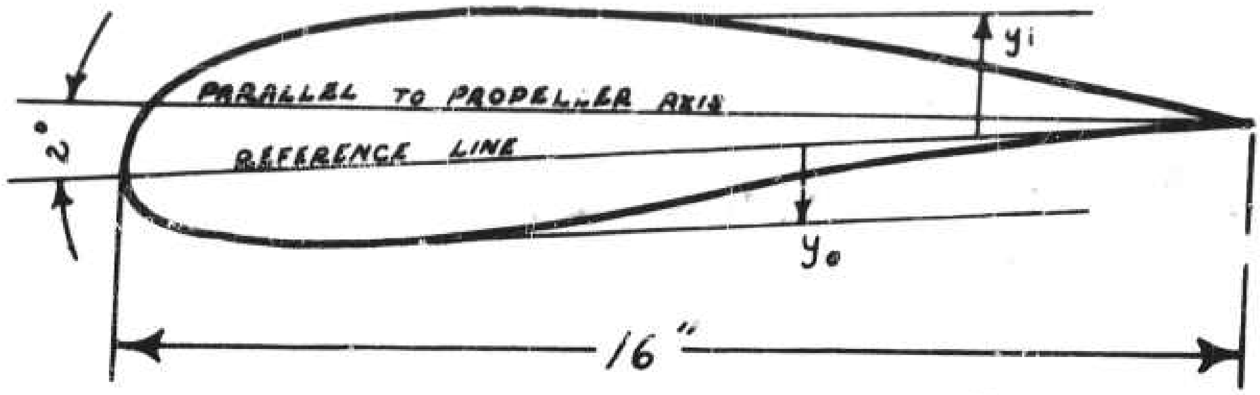
Hubbard, Harvey H. Sound Measurements for Shrouded Propellers at Static Conditions. (NACA Technical Note No. 2024). (Washington, D. C., 1950).

Krüger, W. On Wind Tunnel Tests and Computations Concerning the Problem of Shrouded Propellers. (NACA Technical Memorandum No. 1202). (Washington, D. C., 1949).

Norbury, J. F. and Crabtree, L. F. A Simplified Model of the Incompressible Flow Past Two-Dimensional Aerofoils With a Long Bubble Type of Flow Separation. Royal Aircraft Establishment Technical Note No. AERO 2352, 1955.

Platt, Robert J. Static Tests of a Shrouded and an Unshrouded Propeller. (NACA Research Memorandum No. L7H25). (Washington, D. C., 1948).

Stone, Arthur. A Study of Shrouded vs Unshrouded Propellers. (Department of the Navy, Bureau of Aeronautics Research Division Report No. DR-1750). (Washington, D. C., 1955).



SHROUD SECTION ORDINATES

x STATION % CHORD	y_i INTER SURFACE	y_o OUTER SURFACE
0.0	0.0	0.0
1.25	0.75	0.52
2.50	1.00	0.73
5.0	1.30	0.93
7.5	1.52	1.00
10.0	1.70	1.02
15.0	1.92	1.10
20.0	2.07	1.12
25.0	2.15	1.11
30.0	2.17	1.07
35.0	2.18	1.00
40.0	2.13	0.92
50.0	1.99	0.76
60.0	1.74	0.53
70.0	1.39	0.32
80.0	0.99	0.12
90.0	0.50	0.05
100.0	0.0	0.0

FIGURE 1

MODEL SHROUDED PROPELLER TEST EQUIPMENT

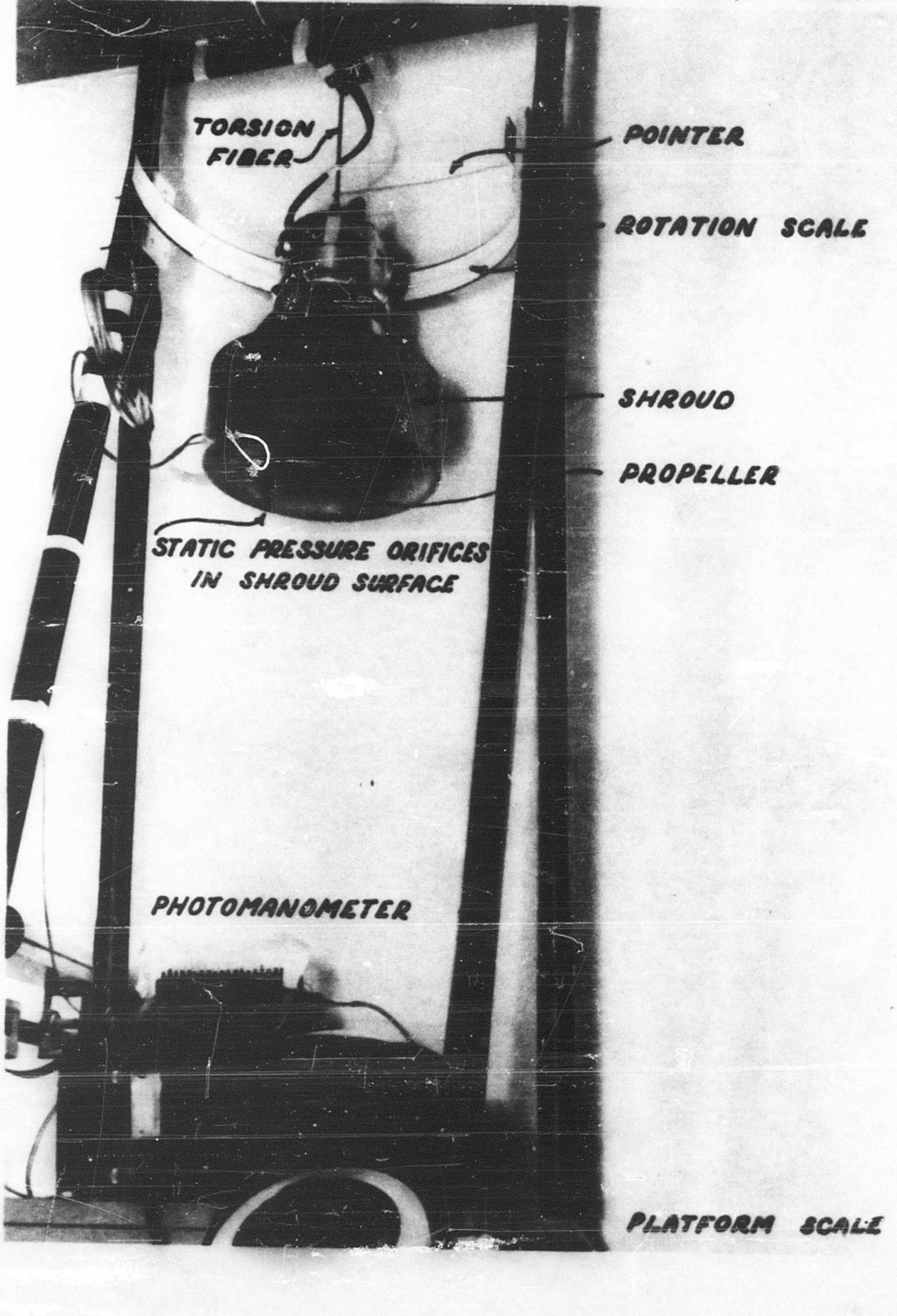
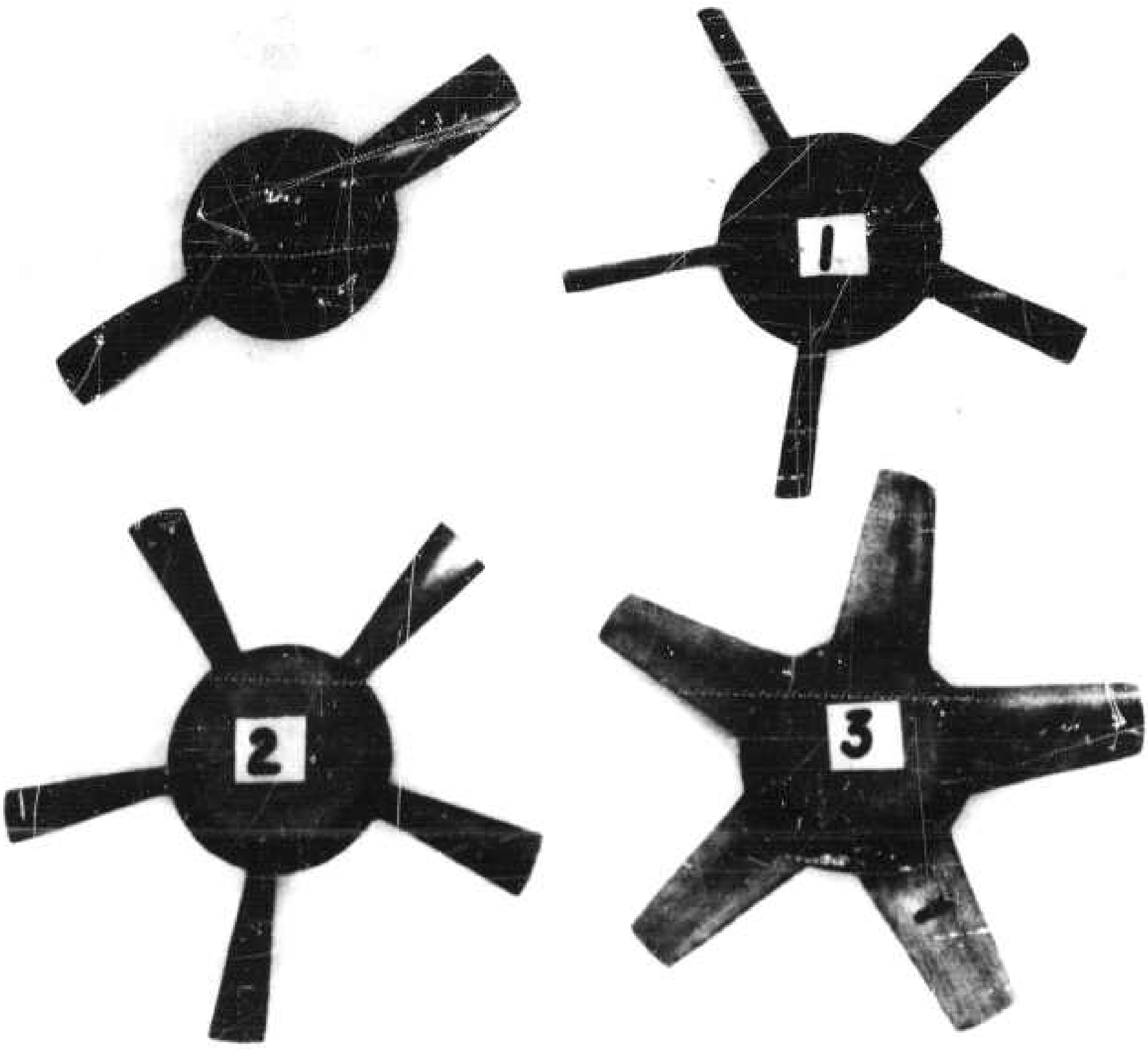


FIGURE 2

MODEL PROPELLERS TESTED



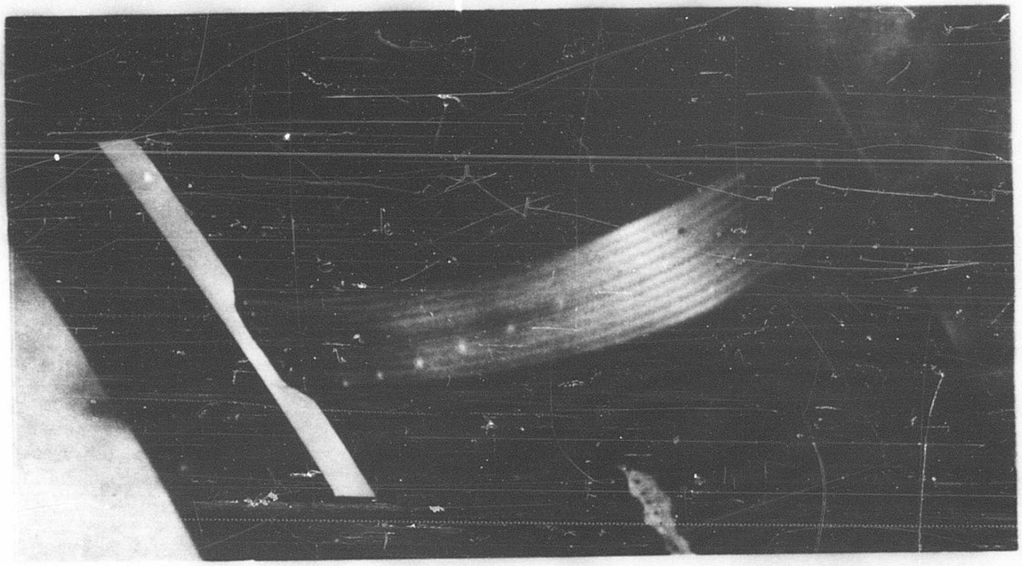
STANDARD MODEL AIRPLANE PROPELLER

PROP. #1 CONSTANT CHORD, UNIFORM PITCH - 45°

PROP. #2 INCREASED WORK AT TIP, UNIFORM PITCH - 20°

PROP. #3 CONSTANT WORK PER EQUAL DISC AREA, UNIFORM PITCH - 20°

FIGURE 3



A. PRESSURE BELT ON FULL SCALE SHROUD

B. SHEAR METER ON FULL SCALE SHROUD

FIGURE 4

VARIATION OF STATIC THRUST WITH DISC LOADING FOR SHROUDED & UNSHROUDED PROPELLER

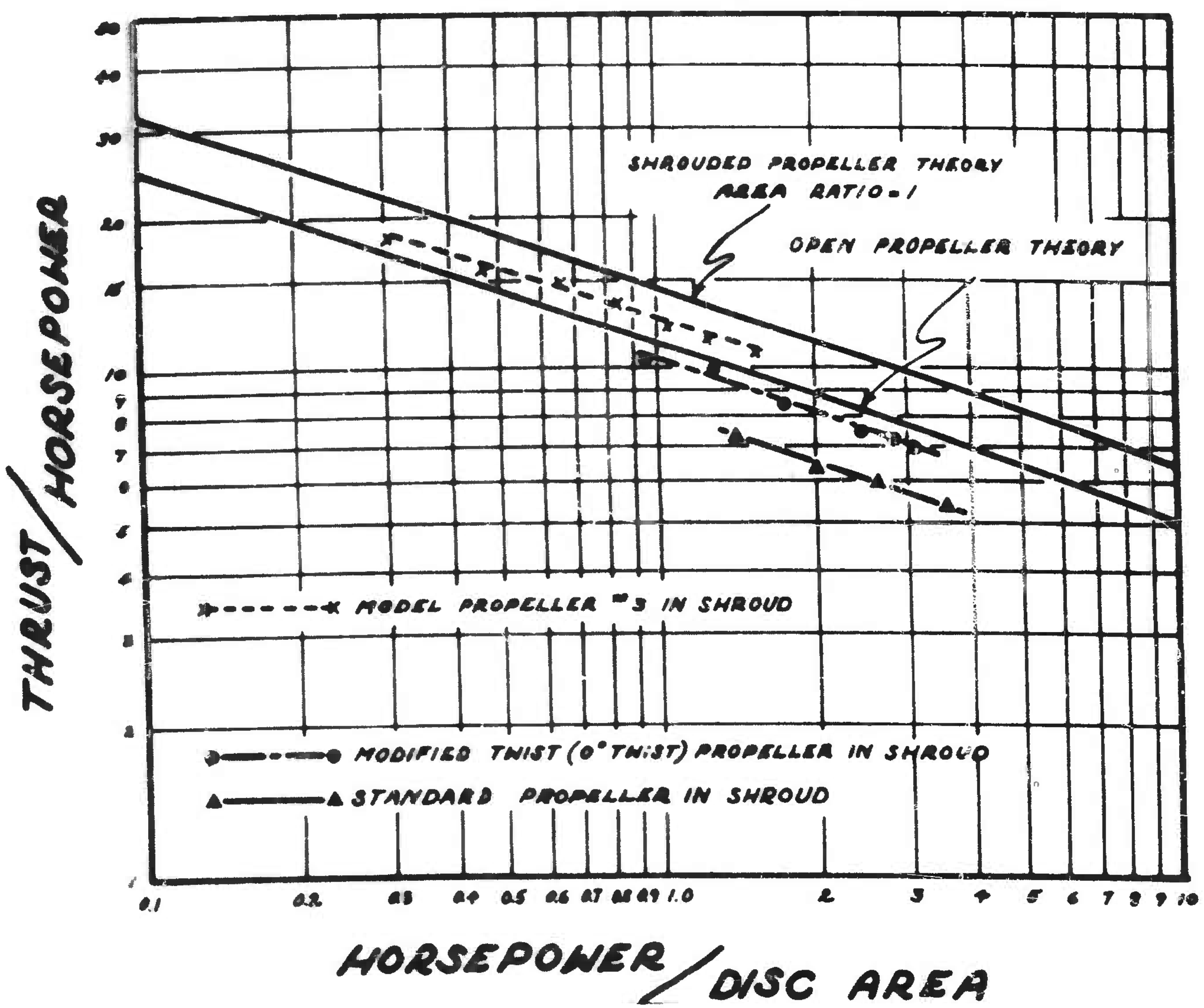
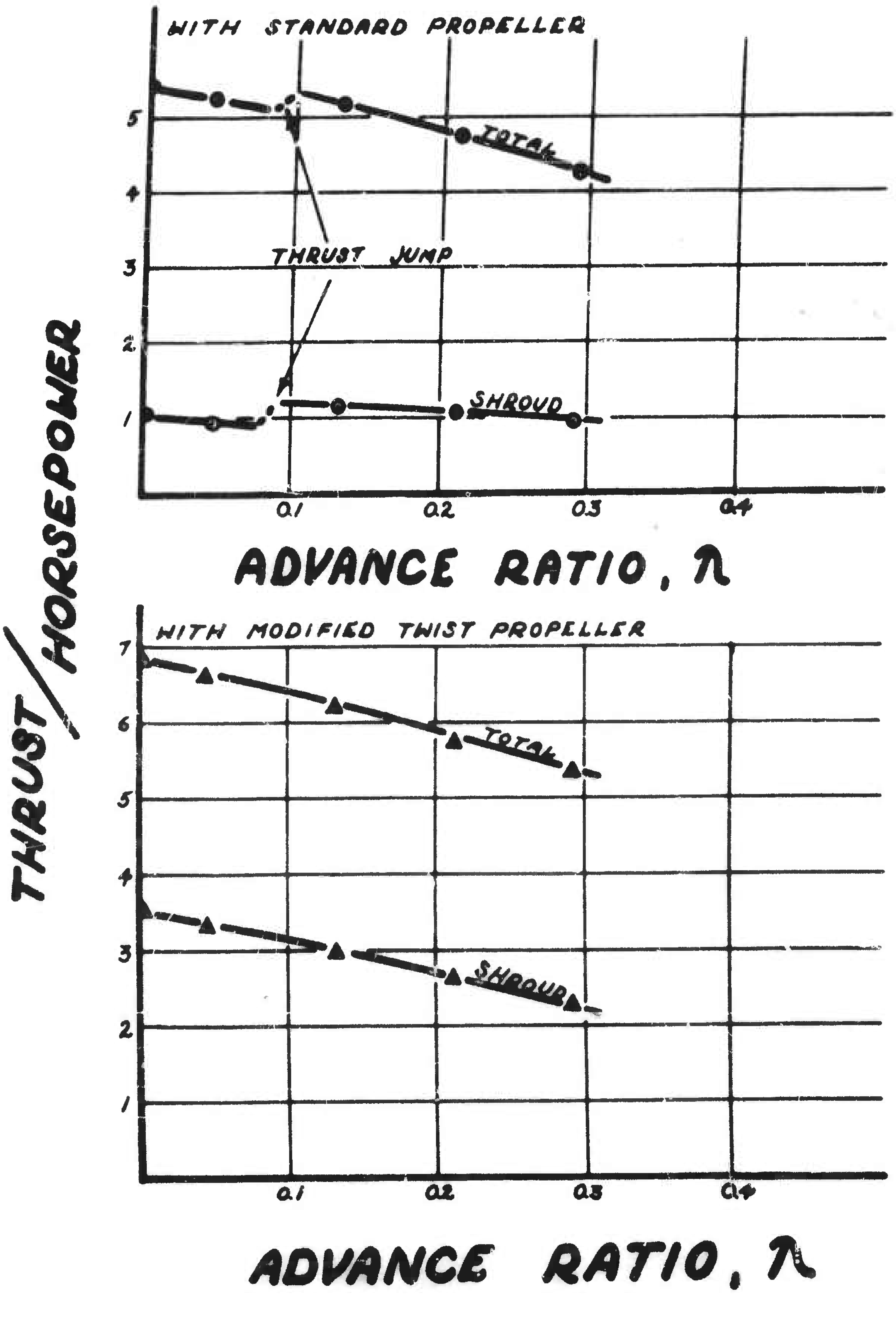
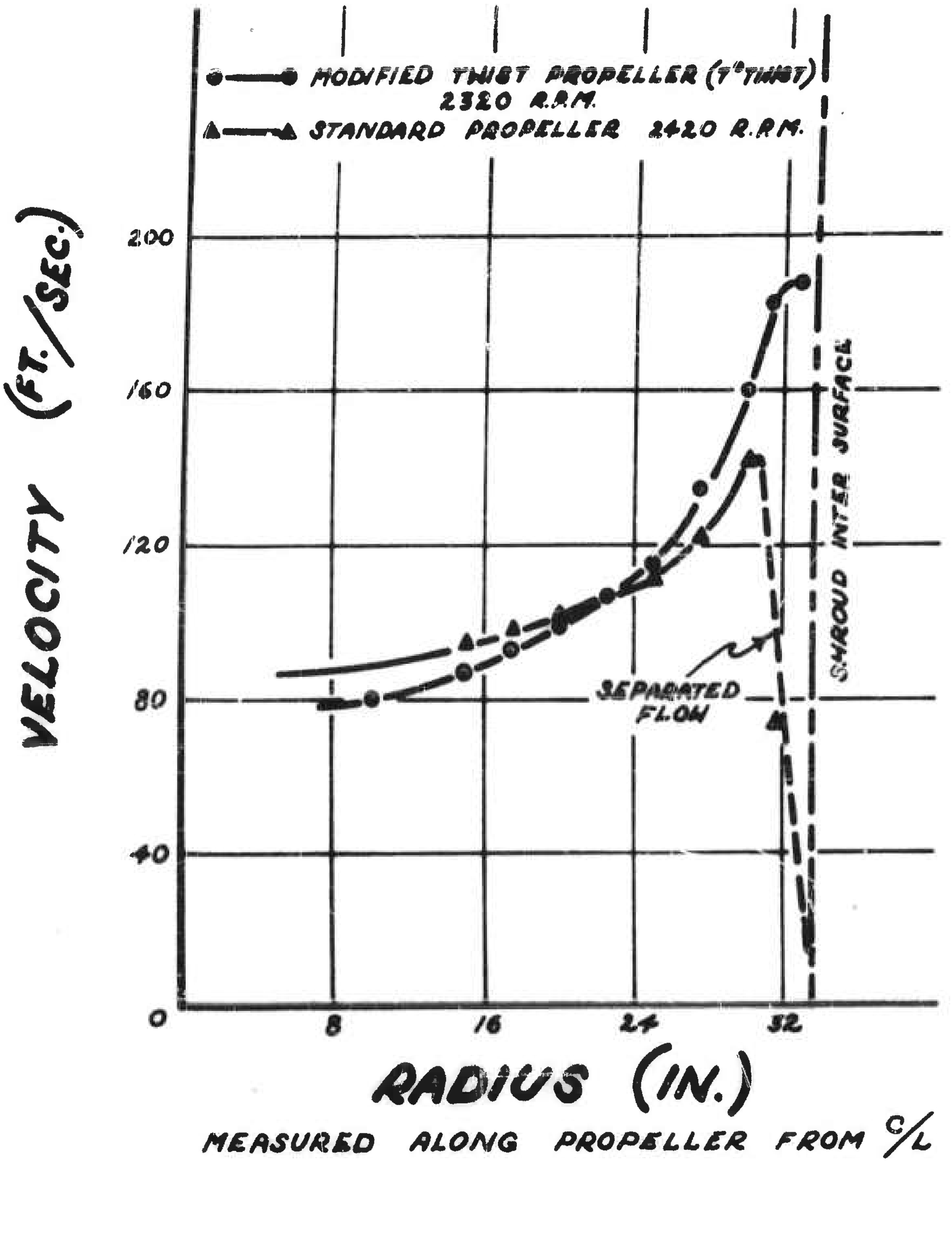


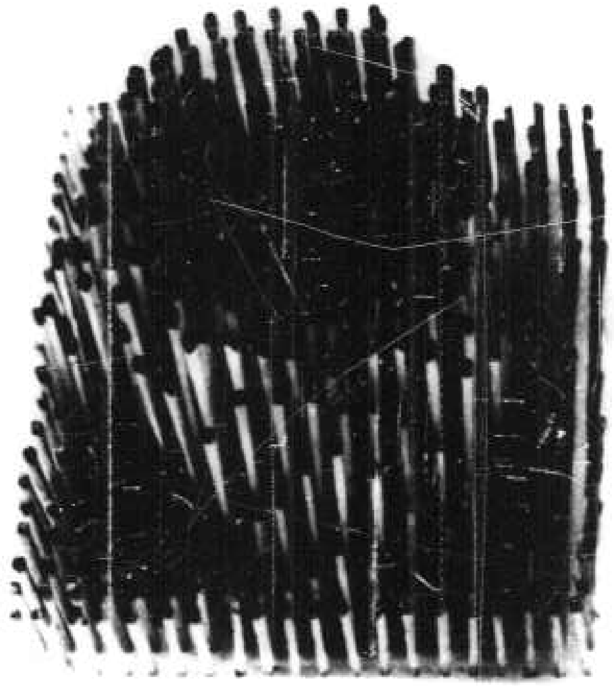
FIGURE 5

THRUST PER HOURSEPOWER AG-14 SHROUD



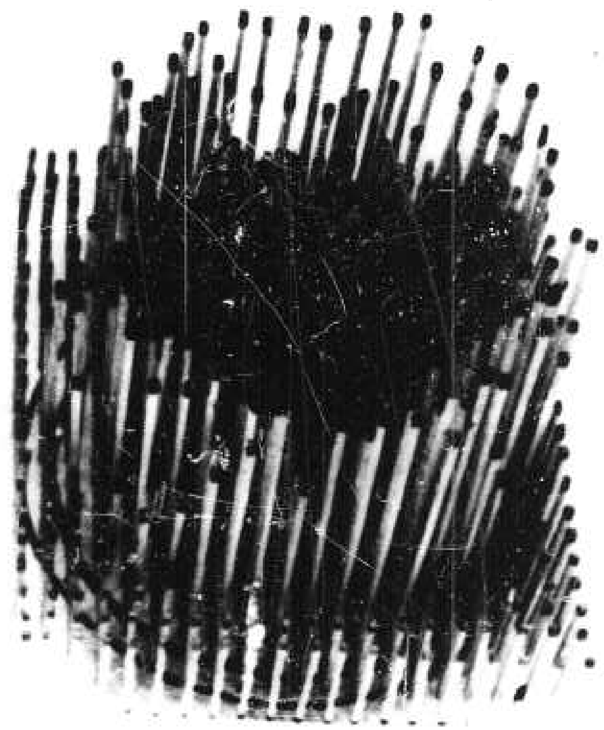
VELOCITY DISTRIBUTION AHEAD OF PROPELLER AG-14 SHROUD, STATIC





AG-14 SHROUD
WITH STANDARD PROP

$\frac{THRUST}{HP} = \frac{466\ LBS}{77} = 6.05$



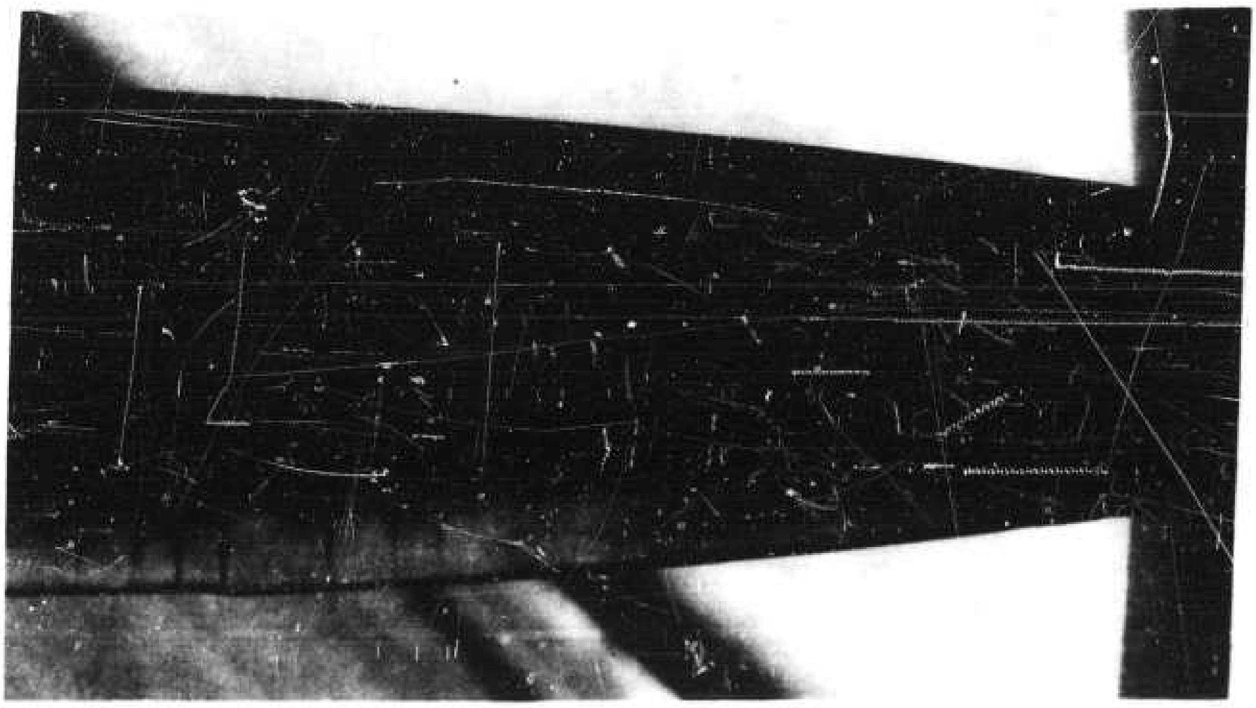
AG-14 SHROUD
WITH MODIFIED TWIST PROP

$\frac{T}{HP} = \frac{550\ LBS}{81} = 6.80$

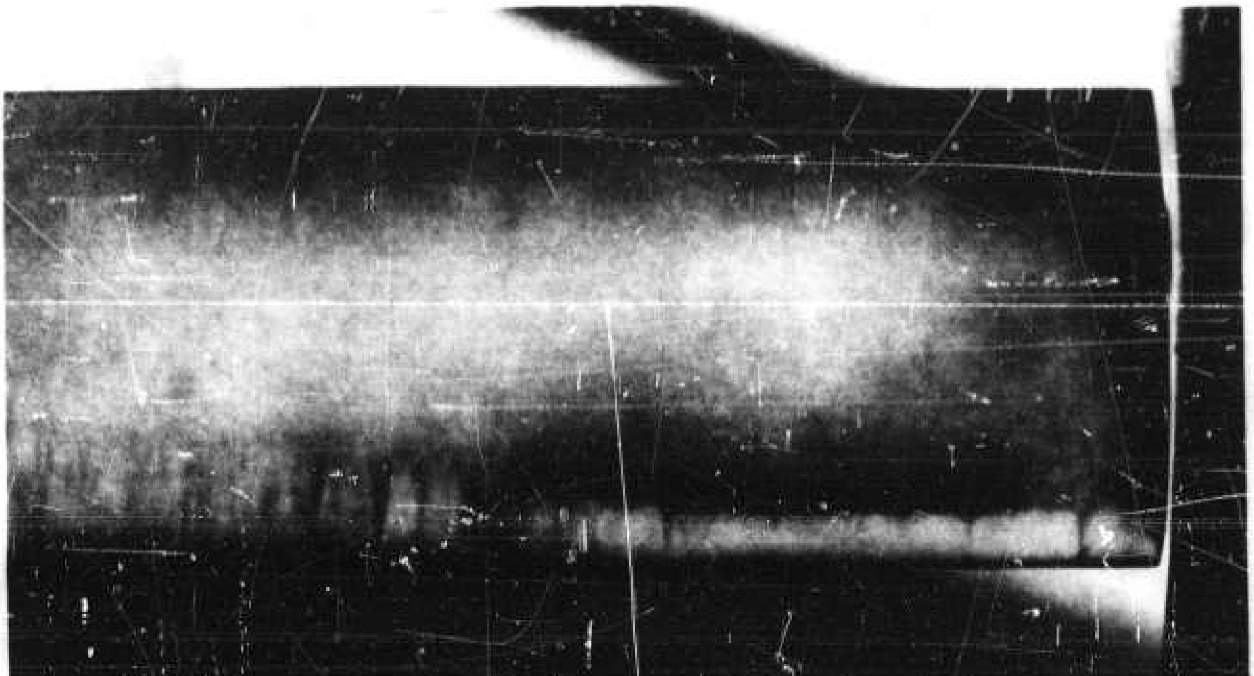
STICK MODELS OF THE VELOCITY PROFILES
AT THE EXIT OF THE SHROUD

FIGURE 7

SUBLIMATION STUDY OF PROPELLERS IN THE SHROUD
STATIC CASE



STANDARD PROPELLER TIP

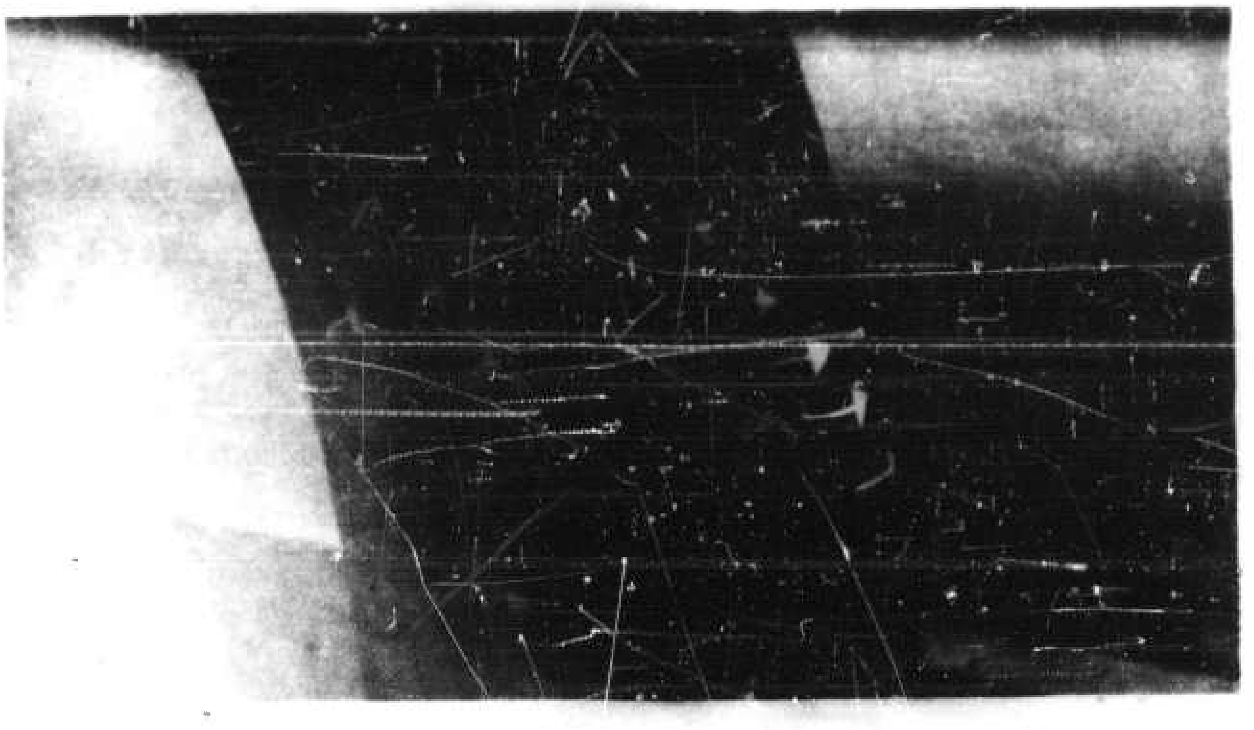


MODIFIED TWIST PROPELLER TIP

FIGURE 9

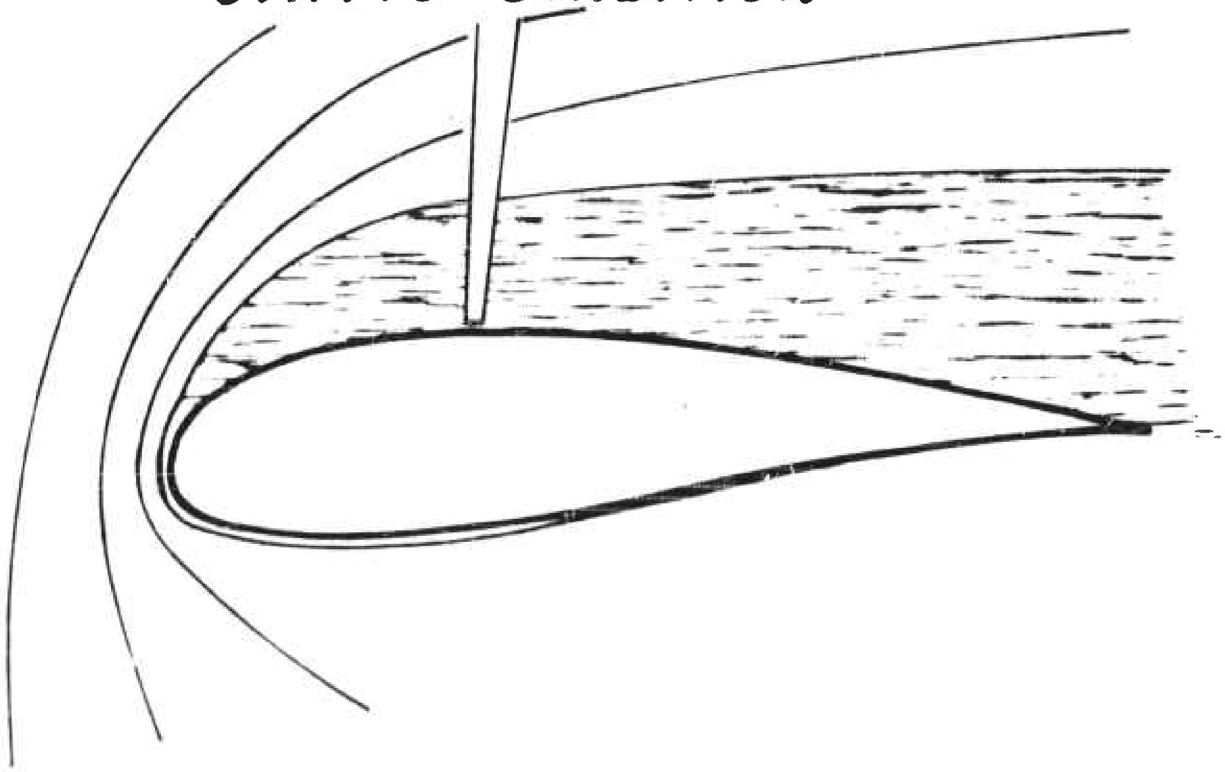
TUFT STUDY OF SHROUD LEADING EDGE FLOW
STATIC CASE

STANDARD PROPELLER IN SHROUD

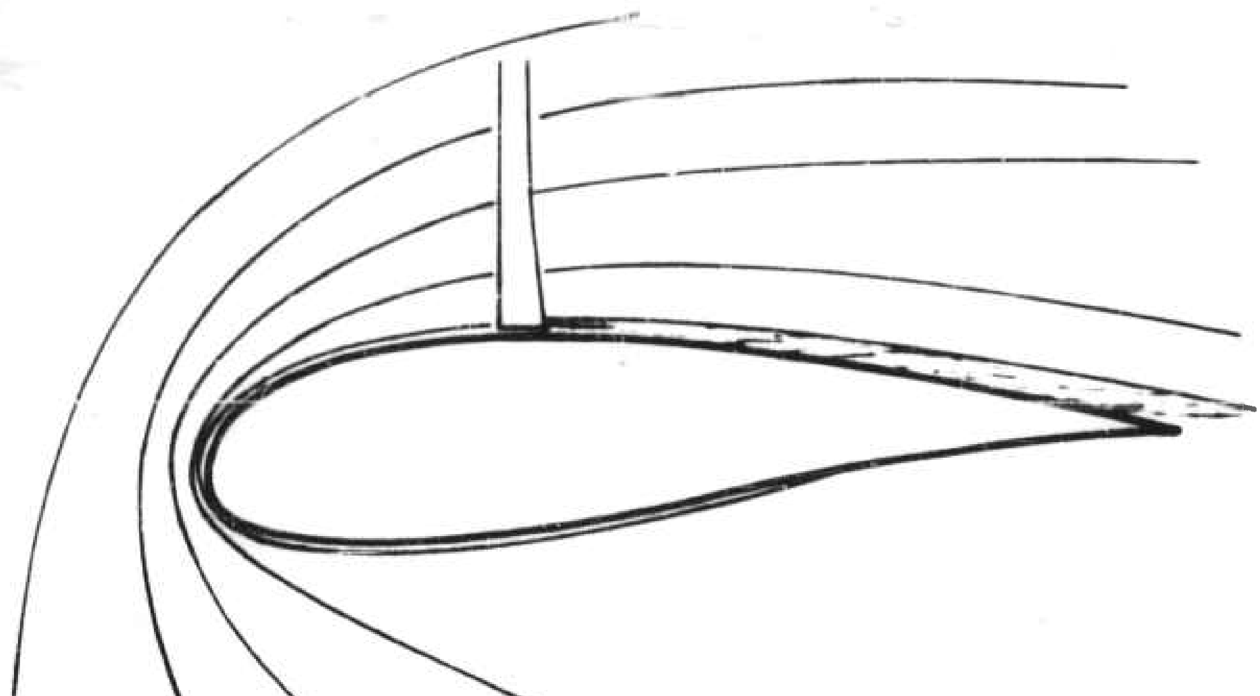


MODIFIED TWIST PROPELLER IN SHROUD

FLOW AROUND SHROUD
STATIC CONDITION



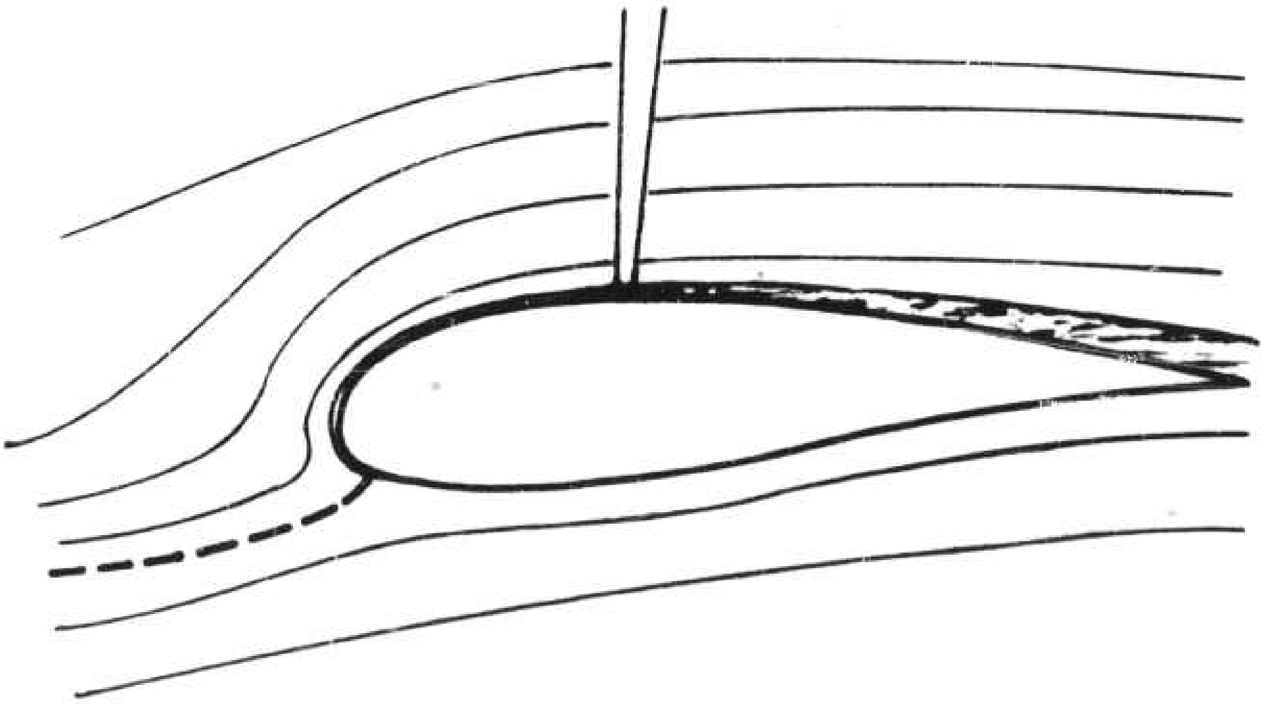
STANDARD PROPELLER



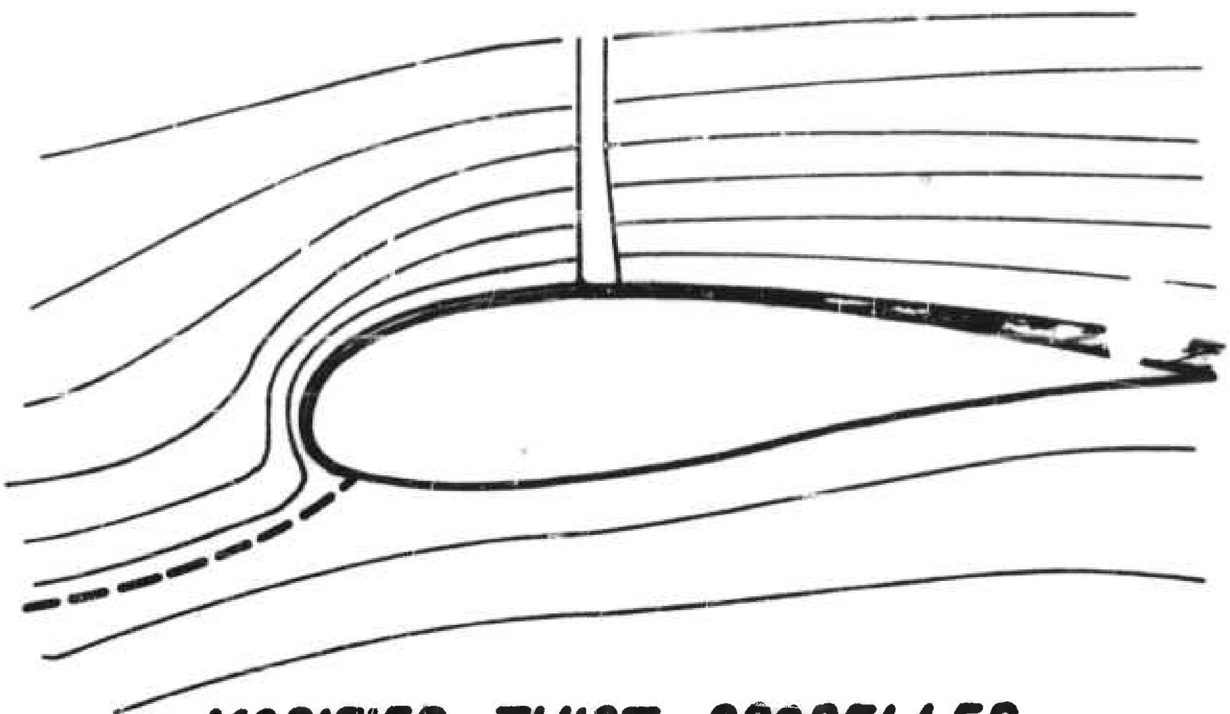
MODIFIED TWIST PROPELLER

FIGURE 11

FLOW AROUND SHROUD
50 M.P.H.



STANDARD PROPELLER



MODIFIED TWIST PROPELLER

TYPICAL VELOCITY DISTRIBUTIONS AROUND LEADING EDGE OF AG-14 SHROUD

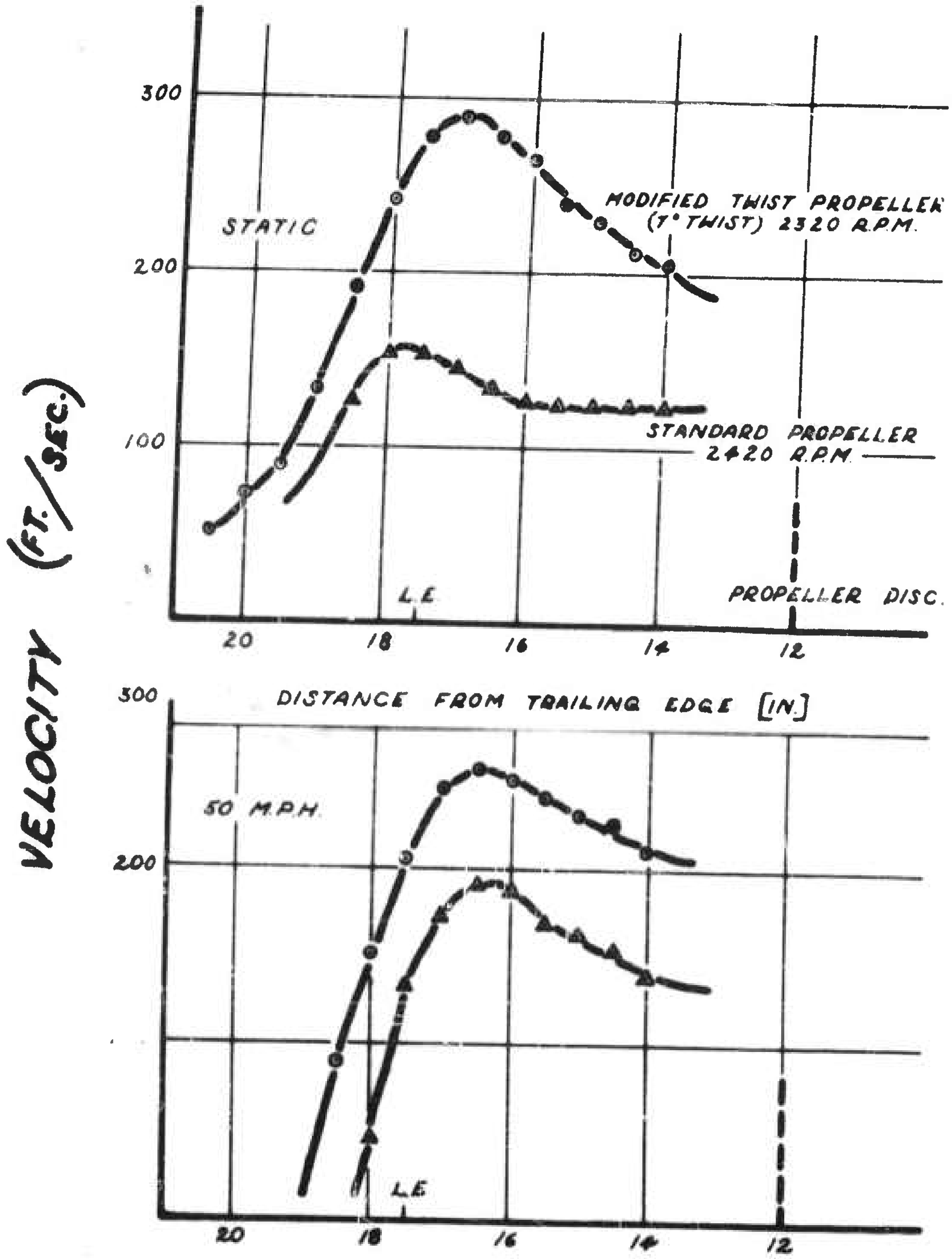
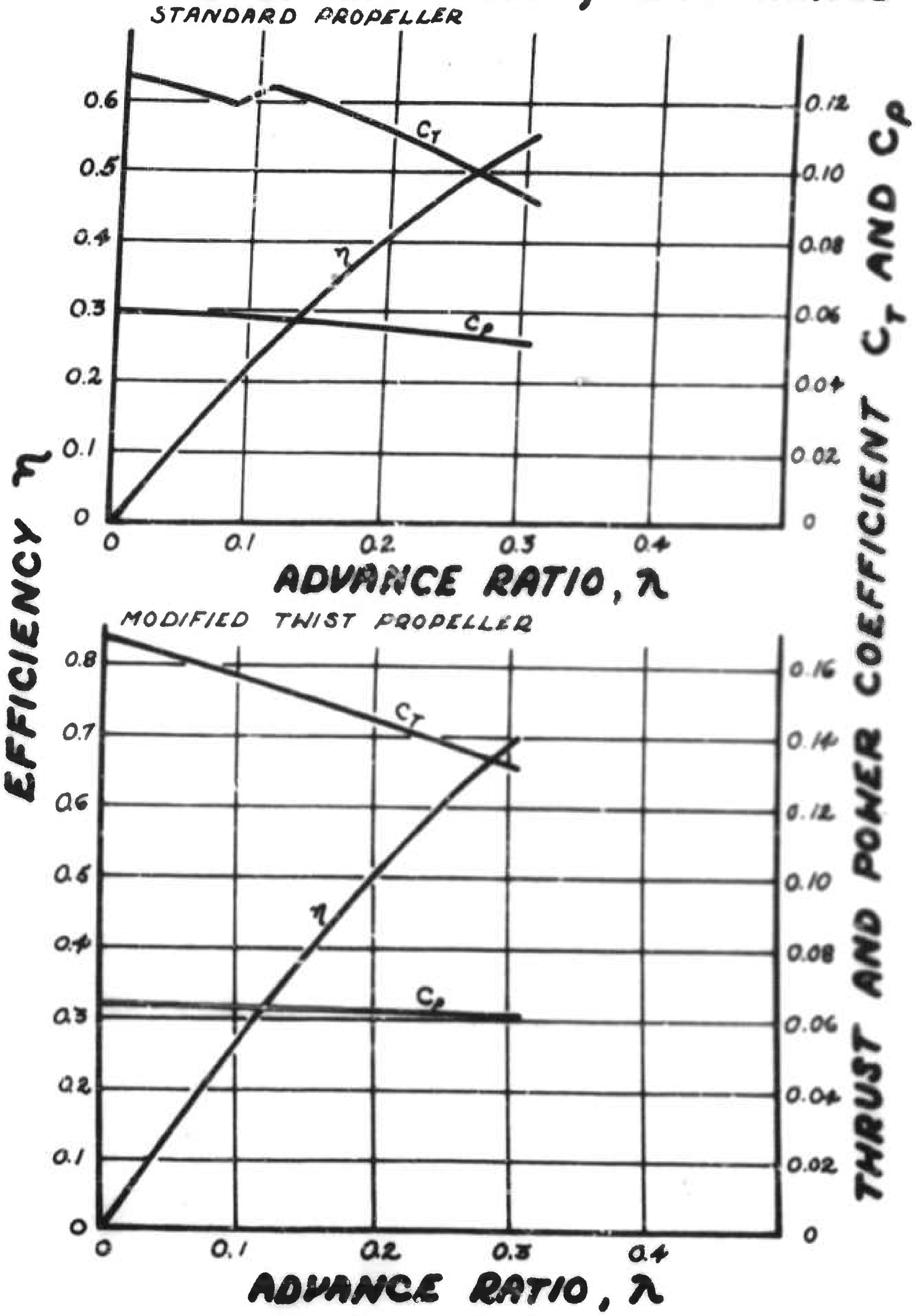


FIGURE 13

SUBLIMATION STUDY OF MODIFIED TWIST PROPELLER
20 MILE PER HOUR CASE

FIGURE 14

PROPULSIVE EFFICIENCY, AG-14 SHROUD



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